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An Evaluation of the Touch Tablet as a Command and Control Input Device

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Four studies conducted to evaluate the touch tablet as an input device to support operator computer communication are presented. Tasks performed by operators in these studies included text editing, two-dimensional compensatory tracking, alphameric and numeric data entry, an analog of a command and control composite task consisting of single function selection, and multiple function selection and data entry.

An absolute mode of tablet operation, in which the table generates x-y coordinates representing the point of touch relative to the physical surface area of the tablet, proved to be superior to a relative mode of operation, in which the tablet is programmed to respond to changes in x-y coordinates, irrespective of the area of the tablet surface activated.

Significant variation in speed and accuracy of performance was observed across a variety of tasks as a function of the mechanism used to signal the computer to accept data emanating from the tablet. A lift-off only mode produced the most rapid rate of response but also the most errors. The most efficient method was the use of an off-table response key to signal the computer to accept the x-y coordinate generated from the touch tablet at each response.

Stylus type also proved to be an important parameter of tablet operation with the use of a hand-held stylus superior in both speed and accuracy to the use of the unaided finger.

Performance with the tablet appears to be consistent, at least with respect to speed of responding, across a wide range of tasks.

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Introduction

A large number of input devices exist which might be considered by the designer of an interactive system. Foley and Wallace propose a classification scheme which groups input devices according to their functional similarities. The four categories are:

1. Pick devices: to process object-identification;
2. Locator devices: to indicate a position and/or orientation;
3. Valuator devices: to input a single value in the space of real numbers; and
4. Button devices: to select from a set of possible choices.

Other classifications have also been proposed. In 1982, Foley and Van Dam added the keyboard as a fifth category due to its universality.

Foley, J. D. & Wallace, V.L. (1974). The art of natural graphic man-machine conversation. Proceedings of the IEEE, 62(4), 462-471.

Ohlson, M. (1978, November). System design considerations for graphics input devices. Computer, 9-18.

Foley, J. D. & Van Dam, A. (1982), Fundamentals of Interactive Computer Graphics Reading, MA: Addison-Wesley.

The only natural pick class device is the lightpen, a direct graphical device used for cursor placement, item selection, command construction, and for interactive graphical dialogues.

A variety of data entry devices are classified as locator devices. One of the most commonly used locator devices is the tablet (or digitizer), a flat surface over which a stylus or the operator's finger may be moved. Additional locator devices include the joystick (both movable and isometric), trackball, the mechanical mouse, and touch panels.

Valuators, devices which provide scalar values, are mostly based on the potentiometer. Dials (rotary potentiometers) are the most common valuators. Slide potentiometers, which use linear movement rather than rotation, are also frequently used valuators. A single axis of a joystick or tablet can be used directly as low resolution valuators. In pairs, valuators can be used as two-dimensional locators.

Button devices are used to identify or select functions. Buttons, such as cursor control keys (step keys) and function keys (text keys), are special types of momentary

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Ramsey, H. R. & Atwood, M.E. (1979, September) Human Factors in Computer Systems: A Review of the Literature (Tech. Rep. SAI-79-111-den). Engelwood, CO: Science Applications (DD No. ADA075679).

Foley & Wallace, 1974.

Ohlson, 1978.

switches that rebound after being depressed. The chord keyboard is another button device.

These various data entry devices are used for five main types of input tasks:

1. Text input,
2. Input of numerical quantities,
3. Selection of commands or operands from a display (menu selection),
4. Discrete positional ("graphical") input, and
5. Continuous positional (e.g., tracking) input.

The Touch Tablet Device

Of primary interest to the present series of studies is the touch tablet, the input device employed with the Lightweight Modular Display System. The LMDS is proposed as a general purpose operator-system interface for surface command and control systems. Operator-LMDS communication is accomplished through a touch-sensitive digitizer tablet and a high-resolution CRT display. All five of the input types listed above are intended to be achieved through the medium of the touch tablet device. The touch tablet is believed to

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Rochester, N., Bequaert, F. C. & Sharp, E. M. (1978, December). The chord keyboard. Computer, 11(12), 57-63.

Ramsey & Atwood, 1979.

Gomez, A.D., Davenport, E.W., Wolfe, S.W. & Calder, B.D. (1982, February). LMDS Lightweight Modular Display System. NOSC Technical Report 767 (TR67), Naval Ocean Systems Center, San Diego, CA.

provide several advantages as an input device in the operational environment: it is durable and requires little maintenance; it consumes little electrical power; it's interface is relatively simple; and it permits the configuration of a workstation requiring a relatively small equipment footprint.

A limited amount of empirical research concerning the utility of touch tablet input devices has been reported in the literature. Albert included a data tablet (with puck) among ten input devices which were compared in a cursor positioning task. The 11" x 11" data tablet ranked fifth among the ten input device configurations with respect to positioning speed, and ranked ninth with respect to positioning accuracy. It was surpased in positioning accuracy only by two touch-screen and two light-pen devices (touch-screens and light-pens were used with and without a footswitch to affect data entry). While the data tablet was surpassed by all but one device (trackball) relative to positioning accuracy, Albert did not report pairwise statistical comparisons between the ten devices. Judging from the descriptive results which were reported, most of the devices were quite close to one another in accuracy (only the touch-screen and light-pen, both without

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Gomez et al., 1982

Albert, A. E. (1982, October). The effect of graphic input devices on performance in a cursor positioning task, Proceedings of the Human Factors Society -- 26th Annual Meeting. Seattle, WA.

footswitches, were clearly superior in accuracy).

It is interesting to note that another of Albert's devices could, in fact, be considered to represent a touch tablet device. Albert used a touch screen mounted on a second, non-active CRT in one experimental condition. This arrangement can be considered equivalent to a vertically mounted, absolute positioning touch tablet. This device ranked sixth among the ten devices in positioning speed and fifth in positioning accuracy.

Gomez et al. compared the LMDS type digitizer tablet with a trackball on a tracking/cursor positioning task. Response times were essentially identical for the two devices. Significant differences in positioning accuracy were found with the trackball producing about 1.3 pixel units (.11 inches) less position error, on the average, than the tablet. These authors concluded that the difference in accuracy between the devices was not sufficiently large to disqualify the tablet as an effective input device.

Whitfield, Ball and Bird report a series of experiments comparing a touch screen (on-display touch input device) to a touch tablet (off-display touch input device). Each of the three experiments required subjects to position a cursor on a selected target. The three experiments differed in the

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Gomez et al., 1982 (Appendix A)

Whitfield, D., Ball, R. G. & Bird, J. M. (1983) Some comparisons of on-display and off-display touch input devices for interaction with computer generated displays, Ergonomics, 26(11), 1033-1053.

resolution of the display to which this response was required. In the first (low resolution -- menu selection) experiment the touch screen was compared to touch tablets with and without a separate "enter" key to confirm cursor positioning. Cursor positioning was accomplished as the subjects moved their fingers across either the CRT screen or the tablet surface.

Speed and accuracy were similar for both the touch screen and the touch pad with separate entry key, and these devices were superior to the touch pad without entry key on both measures in experiment 1. The phenomenon of "fall-out error" was observed for the touch pad without entry key. This error is apparently due to subjects' tendencies to roll the finger tip in one direction or another when the finger is lifted from the tablet surface to affect data entry. This movement would frequently cause the x-y coordinates reported by the tablet to "fall out" of the defined target area during the physical lifting of the finger from the surface of the pad.

For experiments two and three the apparatus was modified to discard the x-y coordinates reported by the touch pad during the last 150 milliseconds of the "lift-off" movement. This software adjustment was made to reduce "fall-out errors." For moderate (experiment two) resolution tasks, the response time for the touch screen was superior to that of the touch pad. The touch pad (with adjustment for fall-

out errors) was, however, significantly superior to the touch screen with respect to error rate.

Experiment three compared the touch screen, the touch pad and a trackball in a high resolution positioning task. In this experiment the touch pad was intermediate between the touch screen (fastest) and the trackball (slowest) in response time, and comparable to the touch screen in error rate. The trackball was significantly more accurate than either of the touch devices.

Operational Parameters for Touch Tablet Use

Although the relatively scant literature suggests that the touch tablet is an effective device for operator - system interaction, there are a number of factors unique to its use which have not been systematically investigated. Consideration of the physical properties of the touch tablet suggests the following as important factors which may affect its viability in command and control systems such as the LMDS:

Mode of Operation: Unlike most other input devices, the touch tablet may be configured (through supporting software) to generate x-y coordinates (representing the point of touch) relative to its own physical surface area (absolute mode), or the system utilizing the tablet may be programmed to respond to changes in x-y coordinates, irrespective of the specific area of the tablet surface which is activated

(relative mode). In the relative mode the tablet can function much like a trackball. In the absolute mode, it is possible to configure a touch tablet system to function such that the tablet surface maps the display surface in some fixed relationship. In this mode the tablet can be made to approximate the characteristics of a touch screen or even a membrane keyboard.

Unfortunately research is not available to prescribe the most effective or efficient mode of operation for the touch tablet.

Data Insertion Mode: Another parameter which is of considerable practical importance in configuring the touch tablet based system is the method of signalling the controlling electronics to accept, or to act on, data emanating from the touch tablet. Most tablets are designed to produce an indication of the x and y coordinates which correspond to the position of the operator's finger or stylus. The system may be signalled to act upon this input in a variety of ways. Perhaps the simplest method of accomplishing this purpose is to accept as input the last x-y coordinate prior to removal of the finger or stylus from the tablet surface. Gomez et al suggested that cursor positioning error related to this insertion mode occurred as

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Cohen Loeb, K. M. (1983) Membrane keyboards and human performance, The Bell System Technical Journal, 62(6), 1733-1749.

Gomez et al, 1982, Appendix A

subjects lifted their fingers from the tablet in other than a vertical direction from the tablet surface. Whitfield et al coined the term "fall-out error" for this phenomenon, and demonstrated that it could be reduced by discarding several x-y coordinate values just prior to 'lift-off.' Another approach to reducing this source of error has been the use of a separate entry key to confirm the cursor positioning response intended. There is some suggestion that a separate data entry confirmation may enhance speed of response.

In general, insertion mode has been dealt with as an equipment artifact rather than as a major parameter of touch tablet effectiveness. Systematic examination of this parameter is important to the design of touch tablet-based data entry systems and considerably more empirical evidence than currently exists must be collected before sound prescriptions for insertion mode can be made with confidence.

Stylus Type: The touch tablet is also unique in that it may be activated either with a mechanical stylus (pen, etc.) or with the unaided finger. Indeed many digitizer tablets use a tethered stylus such as a puck. Gomez et al. allowed subjects to choose whether to operate the LMDS type touch pad with a stylus or their finger. Whitfield et al.

Whitfield et al, 1983

Albert, 1982

considered only finger actuation of the touch pad. An ergonomic analysis of the motor control activity invoked by unaided finger versus mechanical stylus would certainly reveal major differences in basic manipulative effort. Finger operation is generally accomplished through relatively gross movements, with emphasis for position control on the elbow. Stylus positioning, particularly over relatively small areas of the tablet surface, involves considerably more hand/wrist control. The use of larger hand-held styli such as the puck probably is intermediate between the two with respect to the fineness of motor control which can be exerted. Unfortunately no empirical research is available to guide the specific selection of stylus type.

System Response Time: Ramsey and Atwood discuss system response time (SRT) as the interval between completion of a given user input and the completion of the computer response to that input. SRT may be further subdivided to include the System Response Initiation Time (SRIT), the time between user input and start of the computer response; and Display Writing Time (WT), the time between the start and completion of the computer response. An additional delay (before acceptance of additional user input) called Artifical Lockout, may be added to SRT in some applications. Most of

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Ramsey, H. R. & Atwood, M. E. (1979, September) Human Factors in Computer Systems: A Review of the Literature, Technical Report #SAI-79-111-DEN, Science Applications, Inc. Englewood, CO.

the empirical research (cited in Ramsey et al, and elsewhere) has been concerned with the potentially disruptive effect of overly long SRT delays between successive operator responses. A different problem faces the designer of the touch tablet based command and control system. Because of the nature of this input device the probability of inadvertant input may be high. Mechanically this problem may be greatest when simple finger/stylus lift-off is selected as the data insertion mode. If the system provides too short a non-responsive interval between acceptance of successive entries the possibility of inadvertant data entry exists, including a 'contact-bounce' type actuation as the finger or stylus is lifted from the tablet. On the other hand, too lengthy a delay is likely to compromise the operator's efficient use of the input device in multiple entry situations. Empirical research is needed to define an optimum SRT and/or artificial lockout for touch tablet systems.

Type of Input Task: As indicated previously the touch tablet may be used to accomplish a wide variety of operator input actions from simple menu selection to alphanumeric data entry to complex tracking functions. It is logical to expect variation in the effectiveness of an input device as a function of task type, although this within-device/between-task analysis has not previously been reported.

EXPERIMENTAL PLAN

The present research consists of four separate experiments designed to evaluate the operational parameters of the LMDS type touch tablet as an input device. The first two experiments utilize the tablet in relatively simple tasks which have been used to evaluate other input devices. Previous research in this laboratory has compared various input devices in both compensatory tracking and text editing tasks. The tasks used in these studies represent relatively well defined data entry tasks which permit the systematic manipulation of the various touch tablet operational parameters discussed previously. Use of these tasks also provides the opportunity to compare performance with the touch tablet to performance on the same tasks with the joystick, trackball, mechanical mouse, lightpen and keyboard.

Swierenga, S. J. & Struckman-Johnson, D. L. (1984, January) Alternative Cursor Control Devices: An Empirical Comparison Using a Tracking Task, Final Report: Task II.3, Subcontract 5SB-79C0159 with Andrulis Research Corp. & Pacific Missile Test Center. Human Factors Laboratory, University of South Dakota.

Struckman-Johnson, D. L., Swierenga, S. J. & Shieh, K. K. (1984, January) Alternative Cursor Control Devices: An Empirical Comparison Using a Text Editing Task, Final Report: Task II.2, Subcontract 5SB-79C0159 with Andrulis Research Corp. & Pacific Missile Test Center. Human Factors Laboratory, University of South Dakota.

The study referred to as Experiment I.A in the present report assesses the touch tablet as an input device in the text-editing or character deletion task, while Experiment I.B examines the tablet in a two-dimensional compensatory tracking task.

Experiment II in the present series evaluates the touch tablet in a simple alphanumeric data entry task which requires the operator to enter strings of letters or numbers by sequentially positioning a cursor over elements of an alphameric or numeric matrix displayed on the CRT.

Experiment III, the final study reported here, utilizes an analog of a combat data entry scenario to evaluate operator performance with the touch tablet in a complex mixture of single function selection, dual function selection and data entry operations.

Apparatus

The apparatus utilized in all four experiments consists of a microcomputer controlled touch tablet system configured to approximate the physical layout of the Lightweight Modular Display System.

The digitizer tablet used is an Elographics, Inc. Model E233 H/GT digitizing tablet with an 11" x 11" active surface area. The E233 tablet requires approximately 4 oz. activation force, provides resolution of approximately 1 part in 4000, and shows a typical standard deviation of

error of .04". The E233 is interfaced to the microcomputer through an Elographics, Inc. Model E271-60 general purpose controller which detects touch-down on the tablet, converts x and y analog signals to digital position coordinates, and verifies data transmitted to the microcomputer. The controller/computer interface was accomplished by means of an RS232 serial interface. The touch tablet was actuated with either the subjects' unaided finger or a hand-held stylus. The stylus used in all four studies was an 85 mm long plastic tube with a diameter of 20 mm. The tip of the stylus was a 10 mm diameter plastic ball-bearing.

The operator display for the simulated LMDS system is an Amdec Color II RGB monitor interfaced to the microcomputer. Only monochromatic displays were employed in the tasks used in the present series of experiments. A Tektronix Model 604 Monitor Oscilloscope was used as the display for the tracking task in Experiment I.B.

The microcomputer system used to support the tablet and display is an IBM 5150 PC system equipped with 256KB RAM, two double-sided, dual density 320KB flexible disk drives, IBM Color/Graphics Adaptor, AST Six-Pak (serial & parallel I/O & hardware clock), and an Okidata 83A dot matrix printer. Software to support the tasks used by the various experiments was written in UCSD Pascal.

The methods, procedures and results for each of the experiments are presented separately in the following sections.

EXPERIMENT I.A

The first study of this series examined performance with the touch tablet in a simple cursor positioning task which required subjects to delete extra letters occuring randomly in words displayed on a CRT screen. Two basic parameters of touch tablet configuration were assessed in this study. Two levels of "data insertion mode", or the mechanism to signal the computer system to accept touch tablet input, were evaluated. Simple lift-off signalled the system to accept input whenever the subject lifted his finger from the tablet surface after positioning the cursor over the desired character on the CRT screen. Lift-off plus enter, on the other hand, required the subject to position the cursor over the desired character, lift his finger off the tablet, touch his finger down on the tablet and locate the cursor in an "enter" zone, and again lift his finger off the tablet to command data entry.

The second operational parameter of the touch tablet evaluated in this study contrasted the use of a hand held stylus to the unaided finger as an actuator device for the tablet.

Methods

Subjects.

Twenty male subjects recruited from introductory psychology classes at the University of South Dakota were tested in this experiment. Subjects were awarded extra credit in their classes as a condition of their participation. All had 20/20 corrected visual acuity.

Procedure.

Subjects were seated in front of the simulated LMDS system. Ten subjects were randomly assigned to the "lift off only" and ten to the "lift off plus enter" data insertion mode conditions. Each subject performed the text editing task with both the unaided finger and a hand-held stylus.

Subjects were seated in front of the simulated LMDS system and instructed to use their dominant hand to position the cursor on the CRT screen. Figure 1 illustrates the experimental task. The top line of each screen or trial contained three commands, EXCHANGE, DELETE, and INSERT, and subjects were instructed to position the cursor under the 'DELETE' command to initiate each new trial. The words 'DISPLAY MODE' were then written to the top line of the display to indicate that a trial had started. The subject's task during each trial was to locate 'text errors' within the fifty English words displayed on each screen. 'Text errors' were defined as extra letters within the words

displayed, and a total of 10 errors were included within each trial. The extra letters were presented in inverse video to eliminate performance differences due to the subjects' ability to pick out misspelled words. Subjects used the touch tablet to position the cursor below the text errors and command their deletion. When the subject had eliminated all of the extra letters from a screen the trial ended.

Each subject was presented five practice screens/trials, followed by ten trials using the same actuator mechanism (finger or stylus) as he had used during the practice trials. The subject was then instructed to change actuator mechanism (from finger to stylus or visa-versa) and complete an additional ten experimental trials.

```
! COMMAND:    INSERT    DELETE    EXCHANGE                         !
!                                                                  !
!                                                                  !
!     COLLOR PLAAN CAGES  LOCI LEARNING                            !
!                                                                  !
!    AUDITION  HUNGER  CEREBRAL CAGES  CODE                        !
!                                                                  !
!    EFFECT  THOUGHT  THEORY  HUNGER  GOAL  LOCI                   !
!                                                                  !
!    TIME  CAGES  SLEEEP  SURVEY  VARIABLE                         !
!                                                                  !
!    CEREBRAL  LEARNING  STIMULUS  SURVEY  GOAL                    !
!                                                                  !
!    CODE  NEUROSES  CAGES  EAAR  COLLOR  THEORY                   !
!                                                                  !
!     INSTINCT  PPART  BELL  ANXIETY  GOAL                         !
!                                                                  !
!    SOLUTION  CCASE  SYMMBOLS  CEREBRAL  HUNGER                   !
!                                                                  !
!    EFFECT  NEUROSES  HUNGER  TIME   SOLUTION                     !
!                                                                  !
!    WITNESSS   INSTINCT   ROLLES                                  !
!                                                                  !
!                                                                  !
```

Figure 1: Sample text editing/character deletion display

Experimental Design.

A simple two factor design with one between subjects factor (Data Insertion Mode) and one within subjects factor (Stylus Type), was used to evaluate data from this study.

The measures of the text-editing task performance collected in this study were mean trial completion time and total number of errors across trials. An error was recorded each time the subject entered a cursor position which did not correspond to the location of an inverse video letter.

Data were collected during the last nine trials in each block of ten experimental trials (the five practice trials and the first trial under each stylus/finger test condition were discarded to eliminate practice effects).

Results

Table 1 shows the analysis of variance summary table for mean response time. Main effects for both data insertion mode (F = 29.55, df = 1 & 18, p§.01) and stylus type (F = 8.01, df=1 & 18, p § .01) were statistically significant. The interaction between data insertion mode and stylus type was not significant for this measure. Figure 2 shows the average response time per screen as a function of the two independent variables manipulated in this study. Response times for the lift-off only mode of data insertion were substantially faster than for the lift-off plus seperate enter mode, as might be expected because of the difference in the nature of the motor response required by the two modes. A consistently faster response time was also associated with subjects' use of the stylus than use of the unaided finger in this cursor positioning task.

Table 2 shows the analysis of variance summary table for total errors. The main effect of stylus type was statistically significant in this analysis (F = 20.76, df =1

TABLE 1

Analysis of Variance for Mean Response Time

SOURCE	DF	MS	F
<u>BETWEEN</u> <u>SUBJECTS</u>			
MODE	1	16,895.55	29.55 **
Ss w. Grps.	18	571.72	
<u>WITHIN</u> <u>SUBJECTS</u>			
STYLUS TYPE	1	798.02	8.01 **
STYLUS X MODE	1	32.93	.33
STYLUS X Ss w. Grps.	18	99.67	

** p § .01

& 18, p§ .01), as was the interaction between data insertion mode and stylus type (F = 5.64, df = 1 & 18, p § .05). The data insertion mode main effect was not statistically significant. Figure 3 shows total errors as a function of the two independent variables. The hand held stylus produced consistently fewer errors than did the unaided finger. The interaction between data insertion mode and stylus type is quite apparent in Figure 3, and accounted for by a very large increase in error under the unaided finger by lift-off only condition.

TABLE 2

Analysis of Variance for Total Errors

SOURCE	DF	MS	F
BETWEEN SUBJECTS			
MODE	1	34.22	2.44
Ss w. Grp.	18	14.04	
WITHIN SUBJECTS			
STYLUS TYPE	1	126.02	20.76 **
STYLUS * MODE	1	34.22	5.64 **
STYLUS * Ss w. Grp	18	6.07	

** p § .01

FIGURE 2 : Mean Trial Completion Time as a Function of Stylus Type and Data Insertion Mode

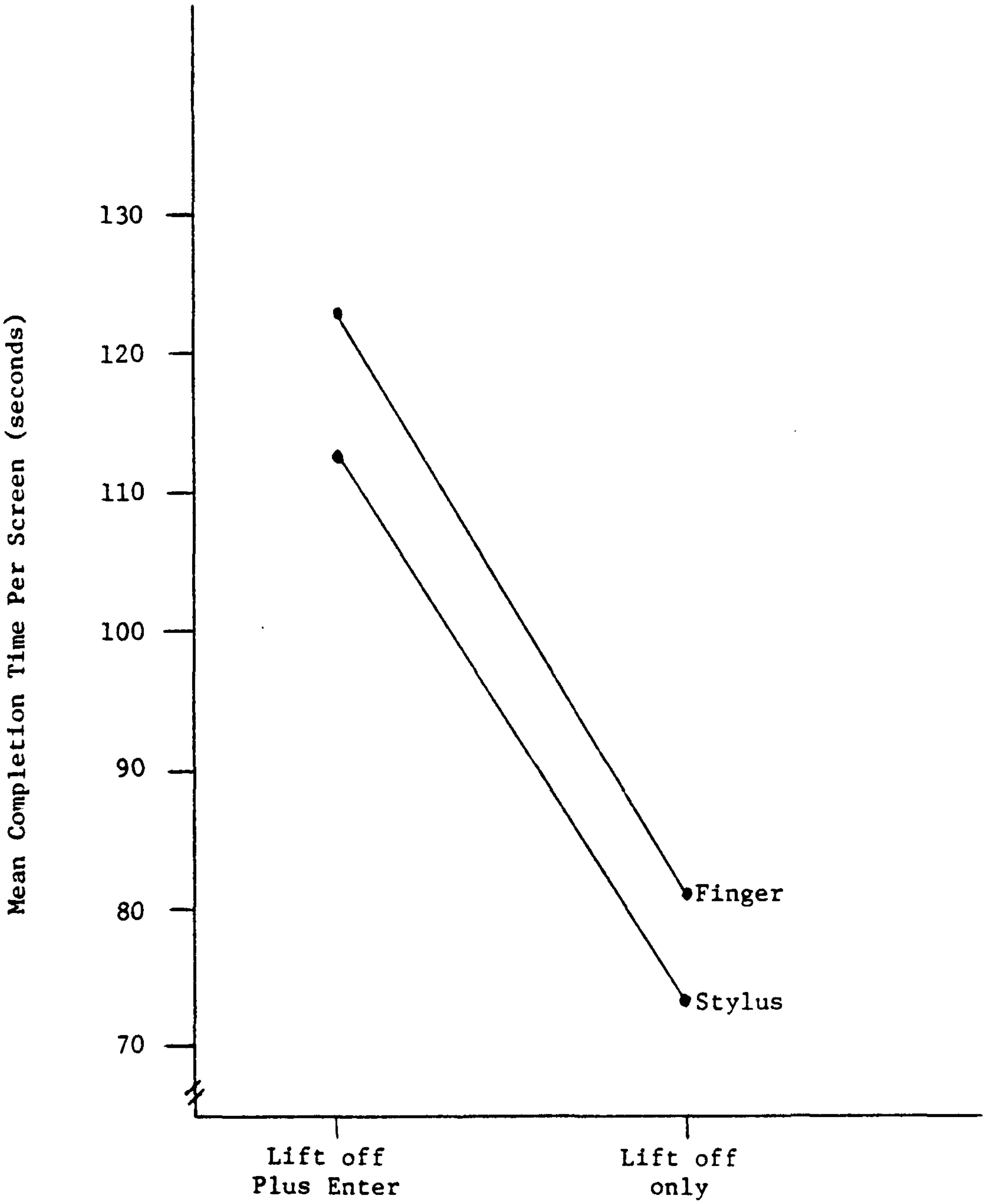
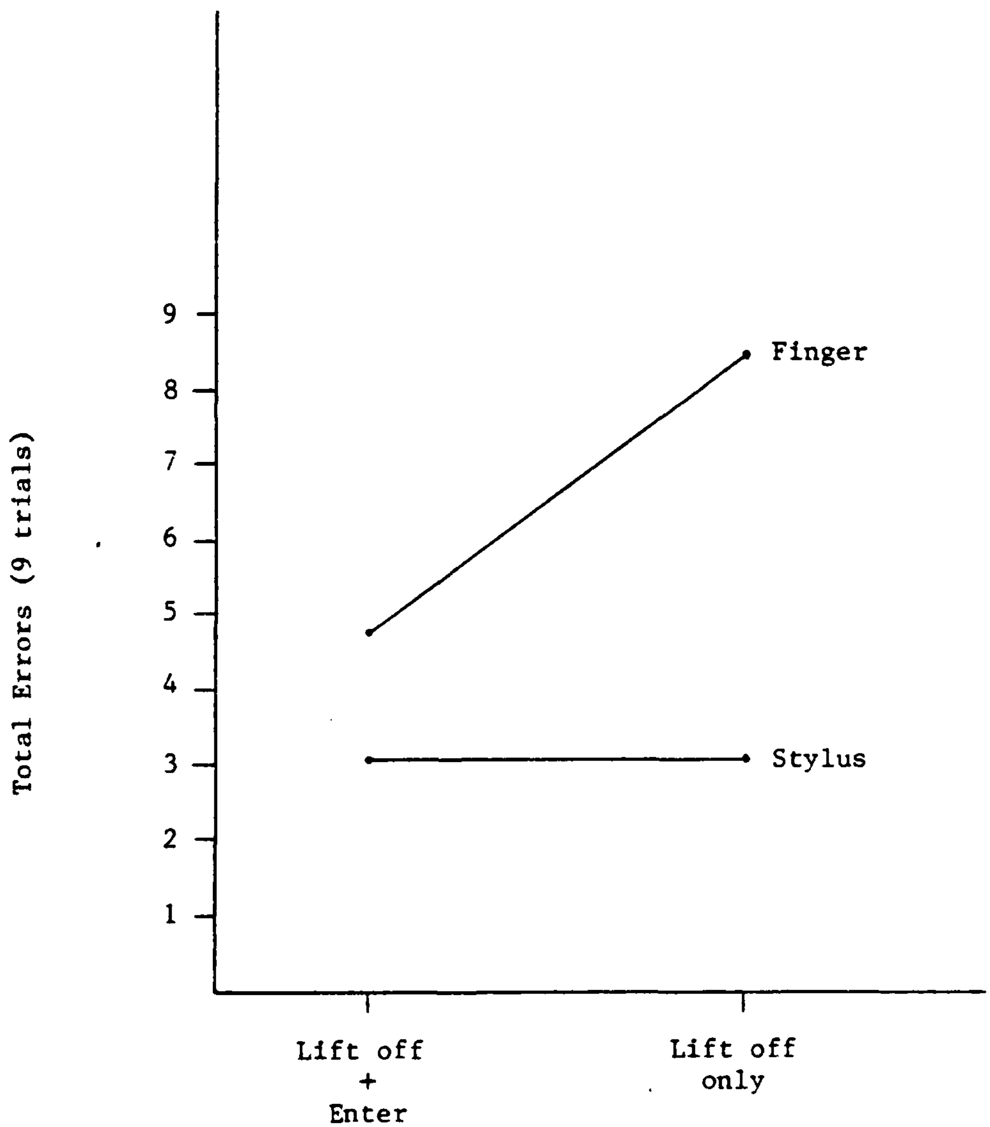


FIGURE 3: Total Errors (9 trials) as a Function of Stylus Type and Data Insertion Mode.



EXPERIMENT I.B

Methods

Subjects.

Forty male subjects were tested in this experiment. All had 20/20 visual acuity (or acuity corrected to 20/20) and all were recruited from introductory psychology courses.

Apparatus.

The digitizer tablet and microcomputer controller used in Experiment I.A were also used in this study. A Tektronix 604 Monitor Oscilloscope was, however, used to present the subject's tracking task display.

Procedure.

Subjects were seated in front of the simulated LMDS console equipped with the touch tablet and the oscilloscope display. Each subject received one level of Mode of Operation (absolute or relative), and both levels (finger and hand-held stylus) of Stylus Type. The tracking task required the subject to use the touch tablet to keep a target cursor superimposed over the stationary cross hairs displayed in the center of the oscilloscope display screen. There were ten trials, each one minute in length. A ten second intertrial rest

period followed each trial. Four samples per second were collected for each of the performance measures descriptive of subjects' tracking performance. The forcing function for the cursor movement was generated by compounding two simple sine waves per axis according to the following formula:

```
VALUE = SIN (OMEGA1 * T + THETA1)
        SIN (OMEGA2 * T + THETA2)
  where OMEGA1 = .1005 radians
        OMEGA2 = .333 radians
        THETA1 = 0 degrees
   and  THETA2 = 54 degrees
```

Experimental Design.

The between subjects variable was Mode of Operation (absolute or relative). The within subjects variable was Stylus Type (finger and stylus). A multivariate analysis of variance was performed on the battery of performance measures. The series of five simple analyses of variance on each performance measure separately was also performed.

Performance Measures.

The performance measures collected included the constant error on each axis, the absolute error on each axis, and the root mean square (RMS) error. Data from trials 2 through 10 of each experimental period were employed in the analyses. The five practice trials, as well as the first trial in each experimental period were discarded to eliminate practice and warm-up effects.

RESULTS

Table 3 presents the results of the multivariate analysis of variance for the battery of five tracking performance measures. Both the Mode of Operation (absolute versus relative) and Stylus Type (finger versus stylus) main effects were statistically significant in this analysis. The interaction between Mode and Stylus Type did not attain statistical significance.

Tables 4 through 8 present the results of univariate analyses of variance for each of the dependent variables separately. It is evident in these tables that RMS error proved to be the most sensitive tracking error measure in discriminating the effects of both Mode of Operation and Stylus Type. Table 9 presents means for each dependent variable under each level of the two independent variables.

TABLE 3

MANOVA Table for Tracking Data

SOURCE	HOTELLING-LAWLEY TRACE	APPROX. F(5,14)	p
MODE of OPERATION	16.25	45.50	.0001
STYLUS TYPE	1.30	3.64	.0255
MODE X TYPE	.43	1.20	.3574

TABLE 4

Analysis of Variance for RMS Error

SOURCE	DF	SS	F	p
BETWEEN SUBJECTS				
MODE	1	1684775.48	110.00	0.0001
Ss w. Grps.	18	275683.21		
WITHIN SUBJECTS				
STYLUS TYPE	1	8371.14	4.96	0.0390
TYPE X MODE	1	4130.04	2.35	0.1430
TYPE X Ss w. Grps.	18	31695.18		

TABLE 5

Analysis of Variance for Constant Error- X axis

SOURCE	DF	SS	F	p
BETWEEN SUBJECTS				
MODE	1	353.75	0.15	0.70
Ss w. Grps.	18	42694.72		
WITHIN SUBJECTS				
STYLUS TYPE	1	2528.95	0.95	0.34
TYPE X MODE	1	2125.18	0.80	0.38
TYPE X Ss w. Grps.	18	47848.77		

TABLE 6

Analysis of Variance for Constant Error-Y axis

SOURCE	DF	SS	F	p
BETWEEN SUBJECTS				
MODE	1	936.60	0.25	0.62
Ss w. Grps.	18	70213.86		
WITHIN SUBJECTS				
STYLUS TYPE	1	129.00	0.02	0.89
TYPE X MODE	1	176.76	0.03	0.87
TYPE X Ss w. Grps.	18	123225.83		

TABLE 7

Analysis of Variance for Absolute Error-X axis

SOURCE	DF	SS	F	p
BETWEEN SUBJECTS				
MODE	1	757558.65	77.45	0.0001
Ss w. Grps.	18	176052.33		
WITHIN SUBJECTS				
STYLUS TYPE	1	797.48	1.04	0.32
TYPE X MODE	1	756.93	0.99	0.33
TYPE X Ss w. Grps.	18	13788.72		

TABLE 8

Analysis of Variance for Absolute Error-Y axis

SOURCE	DF	SS	F	p
BETWEEN SUBJECTS				
MODE	1	612756.39	153.50	0.0001
SUBJ(MODE)	18	71855.53		
WITHIN SUBJECTS				
STYLUS TYPE	1	9422.75	11.01	0.0038
TYPE X MODE	1	3352.38	3.92	0.0634
TYPE X Ss w. Grps.	18	15411.89		

TABLE 9

Means for tracking error measures

	RMS	CE-X	CE-Y	AE-X	AE-Y
ABSOLUTE MODE	272.1	24.2	-1.1	174.4	169.1
TYPE = STYLUS	267.5	24.9	-1.4	174.2	162.9
TYPE = FINGER	276.8	23.6	-0.8	174.5	175.2
RELATIVE MODE	682.6	30.2	8.7	449.6	416.6
TYPE = STYLUS	657.7	45.4	12.6	440.8	392.1
TYPE = FINGER	707.5	14.9	4.8	458.4	441.1
STYLUS ACROSS MODES	462.6	35.2	5.6	307.5	277.5
FINGER ACROSS MODES	492.2	19.3	2.0	316.4	308.2

EXPERIMENT II

Experiment II also attempted to examine basic parameters of the input device under well controlled task conditions. In this study the LMDS type digitizer tablet was used to affect the entry of alpha and numeric data. The chief parameters of tablet operation evaluated were:

1. Data Insertion Mode: lift-off (LO), lift-off plus enter on tablet (LO+E), lift-off plus separate enter key (LO+SE), or no lift-off plus separate enter key (N,SE);
2. Data type: alpha versus numeric data entry;
3. Display Layout Size: the physical size of the displayed alpha or numeric keypads which were the target of cursor positioning; and
4. Subject gender.

Method

Subjects..

Twenty male subjects and twenty female subjects, 18-30 years of age, were tested in this experiment. Each received extra credit in their undergraduate psychology courses for participating. All were tested to confirm 20/20 corrected visual acuity. Informed consent forms were read and signed

by each subject. In addition, subjects received a general written description of the experiment before beginning.

Procedure..

Subjects were randomly assigned to one of four groups - the four levels of Data Insertion Mode - resulting in 10 subjects per group (5 male and 5 female). Subjects in each group were presented all possible combinations of the remaining two factors in a counterbalanced order. The task consisted of entering a 7 character string which was presented on the display at the beginning of each trial. This required that the subject move his or her finger, using the preferred hand, on the touch tablet to move the cursor to the appropriate character within a matrix of alpha or numeric characters. The alpha and numeric 'keypad' areas were either 1 1/2" or 2 1/2" in width and were vertically centered on the right side of the display screen, as shown in Figure 4. In the LO method, data confirmation occurred when the finger was lifted off the touch tablet surface. In the LO+E method it occurred when the subject touched a separate entry zone on the touch tablet. For the LO+SE method, entry occurred when the subject pressed an enter button on either side of the tablet after the finger was lifted off the tablet. In the N,SE mode, the finger remained on the tablet while one of the enter buttons was pressed with the other hand.

Experimental Design..

The two within-subjects variables were: Data Type (alpha and numeric), and Display Layout Size (1 1/2" and 2 1/2" width). The between-subjects variables were Subject Gender and Data Insertion Mode (LO, LO+E, LO+SE, and N,SE). Analyses of variance and other necessary tests were performed on the data.

The measures of the data entry task performance used in these analyses were mean trial completion time and number of errors per trial.

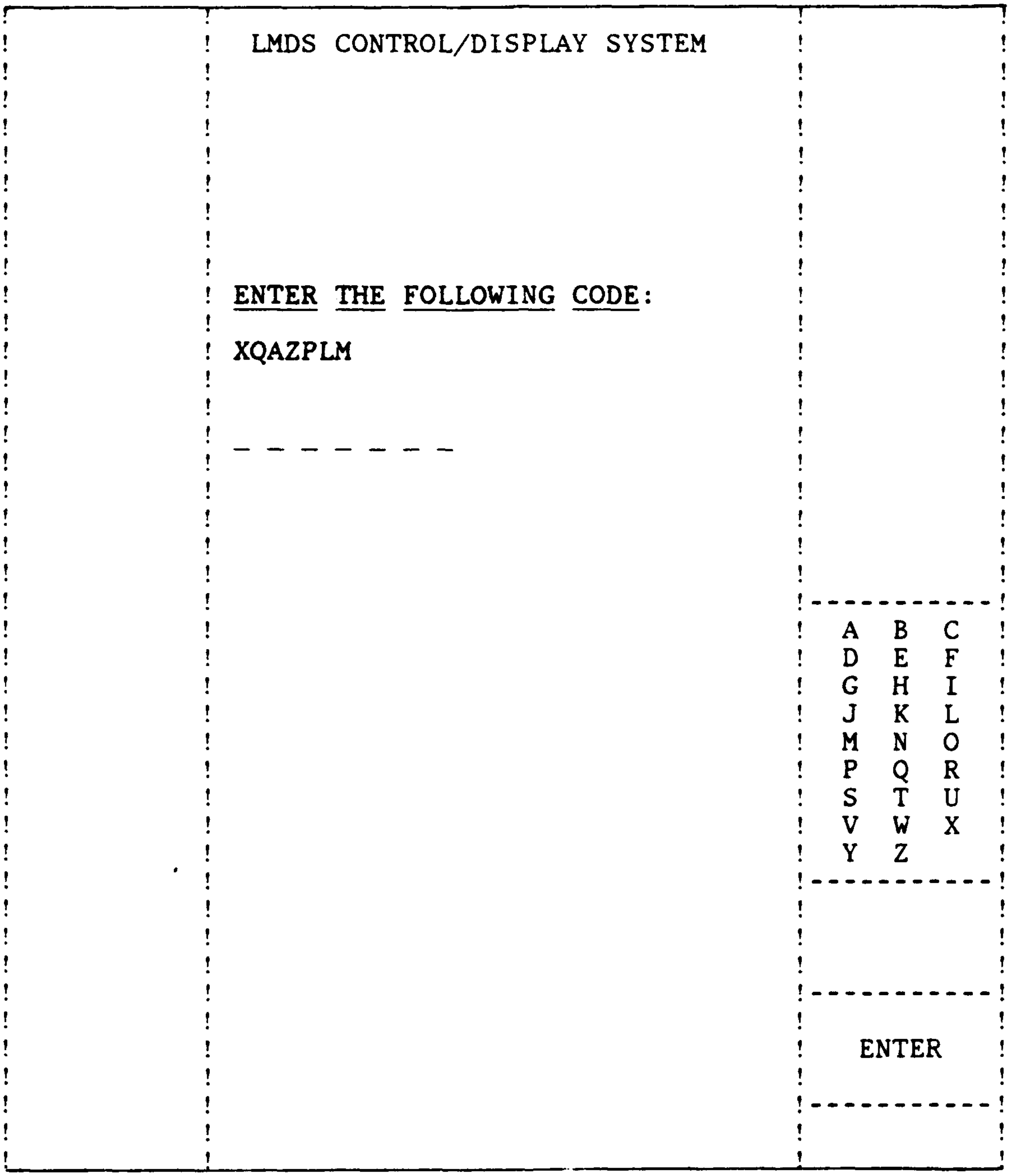


Figure 4: Sample alphameric data entry display

Results

Of the four parameters under consideration in Experiment II, only Data Insertion Mode and Data Type produced statistically significant main effects. In addition, there was a significant mode X type interaction.

The analysis of variance for mean time per screen is contained in Table 10, and these data are plotted in Figure 5. The lift-off plus enter on tablet mode of entry took significantly longer than the other three modes, while the no lift-off/separate enter button was the fastest response mode. Longer times for the lift-off plus enter mode could be accounted f. by the fact that it was the only mode requiring that the cursor be positioned twice for each entry: first under the specified alpha/numeric character and then in the designated enter area on the screen. With the no lift-off, separate enter mode, keeping the finger on the tablet prevented the cursor from "rolling off" of its position and thus did not require repositioning, allowing for faster entry.

Alpha entries took significantly longer than did numeric, and this effect was consistent for all insertion modes. Searching for and positioning the cursor under 1 of 26 alpha characters naturally took more time than doing the same task with 1 of 10 numbers. Another explanation for this effect involves density. For every type of keypad displayed (alpha-small, alpha-large, numeric-small, numeric-large) the

whole tablet corresponded to the keypad area. Finer positioning movements were required for alpha entries, resulting in more time spent on repositioning roll-off errors. There was also a significant Mode X Type interaction, as shown in Figure 5. The lift-off plus enter on tablet mode took only slightly more time for alpha entries than for numeric, while the other three modes show greater sensitivity to the data type effect.

Table 11 presents the analysis of variance for mean errors per screen and Figure 6 plots these data. Again, Insertion Mode, Data Type, and Mode X Type were significant. The mode which took the longest time, lift-off plus enter on tablet, produced the fewest errors. It was easiest to notice and change a mistake before entering it with this mode. Alpha entries led to more errors than numeric for all the modes except lift-off plus separate enter key. It was noted during the experiments that some of the subjects had trouble distinguishing between certain letters in the codes (e.g. M vs. N) due to the resolution of the screen. In the lift-off mode, with no separate confirmation step, it was especially easy to make errors with alpha entries due to the density effect previously discussed. However, errors decreased considerably with numeric entries in the lift-off mode. This single-entry mode could best be used with low density, limited choice displays where speed is important.

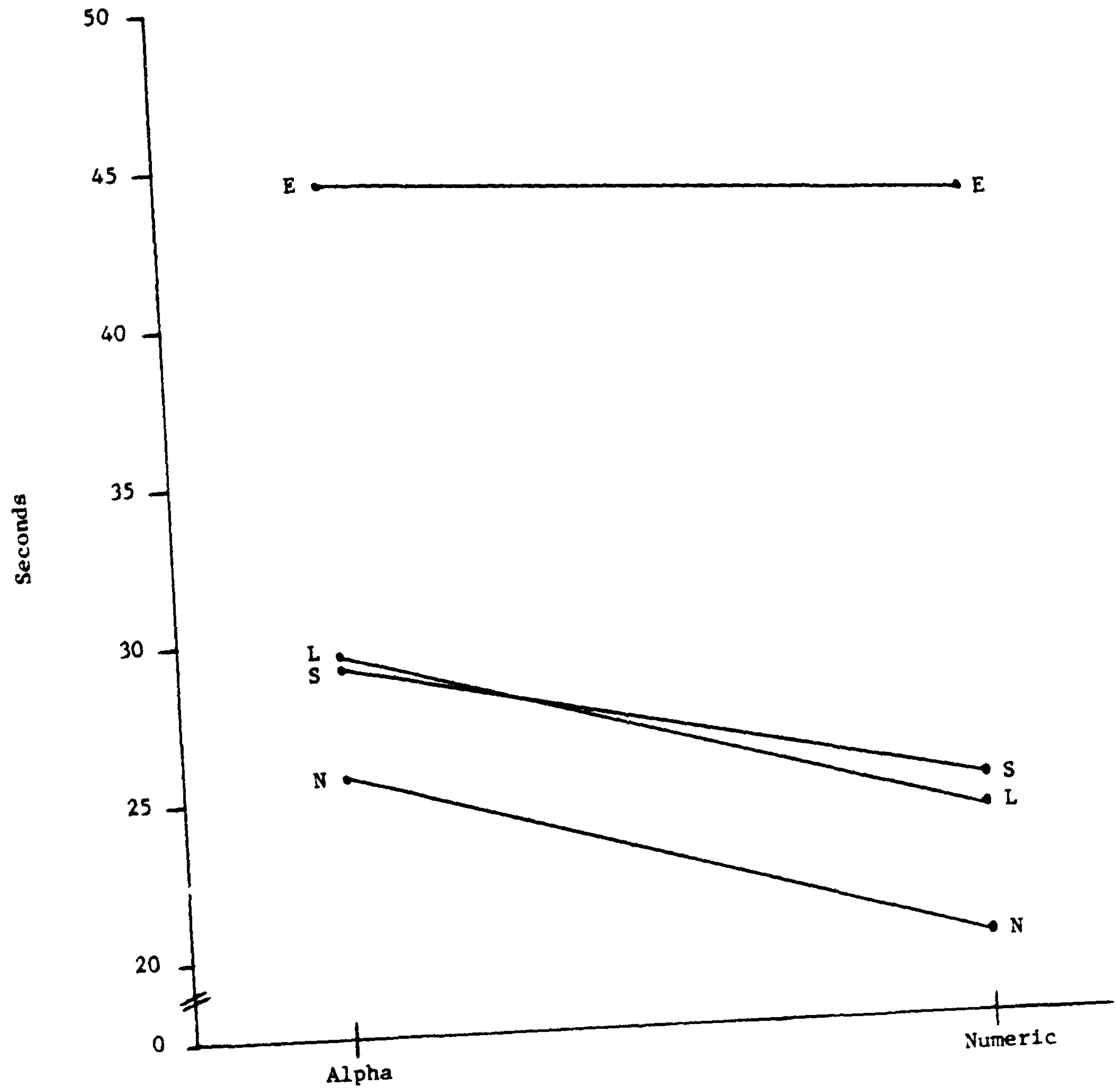
TABLE 10

Analysis of Variance for Response Time

SOURCE	DF	MS	F
BETWEEN SUBJECTS			
GENDER	1	86.72	0.75
MODE	3	3491.02	30.20***
GENDER*MODE	3	24.81	0.21
SUBJ.W.GROUP	32	115.59	
WITHIN SUBJECTS			
DTYPE (ALPHA VS. NUMERIC)	1	637.67	56.41***
DTYPE*GENDER	1	26.51	2.35
DTYPE*MODE	3	46.22	4.09*
DTYPE*GENDER*MODE	3	3.72	0.33
DTYPE*SUBJ.W.GROUP	32	11.31	
SIZE	1	2.55	0.10
SIZE*GENDER	1	1.55	0.06
SIZE*MODE	3	5.24	0.21
SIZE*GENDER*MODE	3	16.70	0.66
SIZE*SUBJ.W.GROUP	32	25.21	
DTYPE*SIZE	1	21.75	2.54
DTYPE*SIZE*GENDER	1	8.76	1.02
DTYPE*SIZE*MODE	3	1.67	0.20
DTYPE*SIZE*GENDER*MODE	3	3.06	0.36
DTYPE*SIZE*SUBJ.W.GROUP	32	8.56	

*** p § .001   * p § .05

FIGURE 5: Mean Total Time per Screen
(Screen = 7 entries)



L = lift-off
E = lift-off plus enter on tablet
S = lift-off plus separate enter key
N = no lift-off, separate enter key

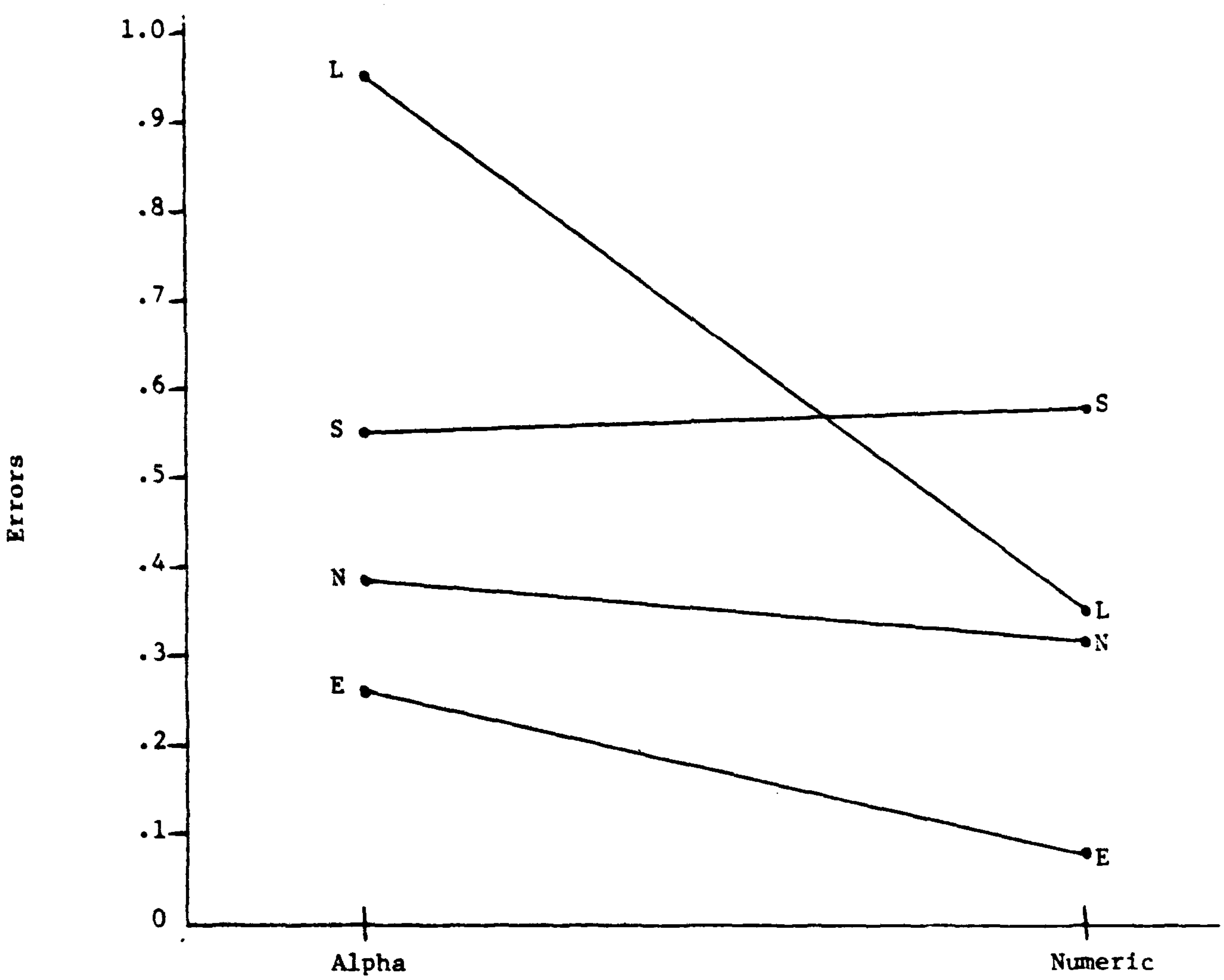
TABLE 11

Analysis of Variance for Entry Errors

SOURCE	DF	MS	F
BETWEEN SUBJECTS			
GENDER	1	0.03	0.07
MODE	3	1.88	4.91**
GENDER*MODE	3	0.28	0.74
SUBJ.W.GROUP	32	0.38	
WITHIN SUBJECTS			
DTYPE	1	1.68	11.51**
DTYPE*GENDER	1	0.04	0.24
DTYPE*MODE	3	0.76	5.23**
DTYPE*GENDER*MODE	3	0.09	0.64
DTYPE*SUBJ.W.GROUP	32	0.15	
SIZE	1	0.06	0.41
SIZE*GENDER	1	0.04	0.29
SIZE*MODE	3	0.02	0.13
SIZE*GENDER*MODE	3	0.19	1.24
SIZE*SUBJ.W.GROUP	32	0.15	
DTYPE*SIZE	1	0.16	1.30
DTYPE*SIZE*GENDER	1	0.00	0.02
DTYPE*SIZE*MODE	3	0.39	3.11
DTYPE*SIZE*GENDER*MODE	3	0.16	1.28
DTYPE*SIZE*SUBJ.W.GROUP	32	0.13	

** p § .01

FIGURE 6: Mean Errors per Screen
(Screen = 7 entries)



L = lift-off
E = lift-off plus enter on tablet
S = lift-off plus separate enter key
N = no lift-off, separate enter key

EXPERIMENT III

In the third experiment an attempt was made to combine several digitizer tablet input types (single function or menu selection, dual function selection, alphabetic data entry, and numeric data entry) in a simplified analog of an actual operator's task.

To avoid the necessity of extended training and the probability of confounding due to differential levels of task familiarity, the task was configured in such a manner that the operator was specifically instructed relative to each step of the task.

Method

Subjects.

Thirty female and thirty male students enrolled at the University of South Dakota participated as subjects. All had 20/20 or better corrected visual acuity. Subjects received extra credit points in introductory psychology classes as a condition of their participation.

Experimental Design.

All the variables evaluated in this experiment were between subjects variables. The independent variables were:

1. Gender: female vs male;

2. Data Insertion Mode: simple stylus lift-off, lift-off plus enter on tablet, and lift-off plus separate enter key; and

3. Stylus Type: unaided finger vs hand-held stylus.

Five female and five male subjects were randomly assigned to each of the six treatment groups: finger & lift-off, finger & lift-off plus enter, finger & lift-off plus separate key, stylus & lift-off, stylus & lift-off plus enter, and stylus & lift-off plus separate key. The measures of the function selection and data entry task performance collected in this study were trial completion time, time spent on each screen, and number of errors per trial. An error was recorded each time the subject commanded the system to accept data (either lift-off or lift-off plus enter key confirmation, depending upon experimental condition) which was not on the specified function or alphanumeric data. In addition to these measures, the overall time was broken down into two parts, one for the function entry subtask (i.e. single function entry vs dual function entry), and the other one for the data entry subtask (i.e. alphabetic vs numeric). These additional subtask variables were treated as within subjects variables and the results of the analyses of overall time and the times spent on subtasks were compared to the results of Experiments I and II.

Procedure.

Subjects were seated in front of the simulated LMDS console and read a general description of the task. This task consisted of two subtasks: one was a function entry subtask; the other was a data entry subtask. Subjects were presented a total of 8 trials with 9 display screens on each complete trial. The first two trials were practice trials. The 9 screens presented in each trial were:

1. On screen 1 subjects were told to select a single function, "AIR", from four options (i.e. OUTERSPACE, AIR, SURFACE, and UNDERWATER).
2. On screen 2 subjects were asked to sequentially select two functions: one was "COMMAND SELECT"; the other one was "COMBAT REVIEW".
3. On screen 3 subjects moved the cursor to the combat classification summary area and selected "WPN SELECT", then went on to select "COMBAT ENTRY".
4. On screen 4 subjects were told to select "MISSILE" as the type of weapon from three options (i.e. missile, nuclear wpn, and laser wpn).
5. On screen 5 subjects were instructed to select "KEYBOARD".
6. On screen 6 there were three 5-letter codes which were to be entered by sequentially positioning the cursor in an alphameric keyboard area. After entering these codes, subjects were instructed to select the "complete" function.

7. On screen 7 subjects were asked to select "SAM" as the group of missiles from eight options (i.e. SSM, SAM, SUM, USM, AAM, ASM, AUM, UAM).
8. On screen 8 subjects were told to select "COORDINATE" as the option for geometry from four options (i.e. BRG, UNIV, RNG, COORDINATE).
9. On the last screen, screen 9, there were three 5-digit numeric codes to be entered from a numeric keyboard area displayed on the screen. After entering these numeric data, subjects selected "complete" to terminate the trial.

The alpha type of data (i.e. codes) consisted of randomly constructed letter combinations restricted to non-syllabic nonsense words. The numeric type of data (i.e. numbers for X,Y,Z) consisted of randomly selected number combinations. All subjects were asked to complete the task as quickly and accurately as possible.

Results

As shown in Figure 7, subjects maintained stable performance after the first two practice trials. Therefore, the analyses were performed on the data of the last six trials.

An analysis of variance on trial completion time showed only a highly significant mode effect (p § 0.0001) (see Table 12). Duncan's Multiple Range Test on this main effect

showed that the average time of lift-off plus enter mode was significantly larger than the two other modes. However, lift-off mode and lift-off plus key mode did not differ significantly (see Figure 8). The stylus effect approached statistical significance (p § 0.057). Subjects using a stylus responded consistently faster on every subtask than those using a finger (see Table 17).

The analysis for the data entry subtasks alone (i.e., alphabetic versus numeric) showed significant effects for Mode (p § 0.0001), Stylus (p § 0.035), Data Type (p § 0.0001), and for the Mode x Data Type interaction (p § 01) (see Table 13). The Lift-Off Only mode was significantly faster than either the Lift-off + Enter or the Lift-Off + Key mode. The Lift-Off + Enter mode was still slower than the Lift-Off + Key mode (see Figure 9). Again, using a stylus was still faster than using a finger (see Figure 10). The Data Type effect was significant because alphabetic data entry took more time than numeric data entry which had only 10 alternatives and a much smaller keypad area. The Mode and Data Type interaction effect indicated that the difference in time spent on two different data entry types was the largest for the Lift-Off + Enter mode.

Since screens 2 and 3 involved dual function entry and screens 4, 5, 7, and 8 involved single function entry, the average function selection time was computed separately for single function entry and dual function entry tasks. The

analysis of average function selection time in the two different function entry tasks showed the significant effects of Mode (p § 0.0001), function entry type (p § 0.0002), and mode and function entry type interaction (p § 0.04) (see Table 14). Basically, these effects were similar to those found in the data entry analysis except that the stylus effect was not significant. Because the data entry subtask demanded more precise movement on the touch tablet, stylus effect was significant for this subtask. This, however, was not the case in single or dual function entry subtasks which required less precise movement on the tablet. The data entry type effect was examined and showed that subjects spent more time to enter each function in the dual function entry condition than in the single function entry condition. However, this effect was almost negligible on lift-off plus key mode because the average difference was only about 0.18 seconds.

The final analysis compared average selection time for two subtasks, data entry and function entry subtasks). The single selection type, mode, and mode and single selection type interaction effects were all highly significant (p § 0.0001) (see Table 15). Duncan's Multiple Range Test on simple selection type effect showed: single letter entry took more time than single digit entry; single function entry of dual entry took longer than single function entry of single entry; single digit entry and single function

entry of dual entry did not differ significantly (see Figure 11). In addition, stylus and single selection type interaction effect was also significant (p § 0.037) (see Figure 12). This confirmed the previous finding that precise movement (i.e. data entry subtask) showed stylus effect while gross movement (i.e. function entry subtask) did not.

In general, the results of this experiment could be concluded as follows:

1. The mode effects showed that the lift-off only mode was the fastest one followed by the lift-off plus key mode and lift-off plus enter mode (see Table 16).
2. Using a stylus required less response time than using a finger. This effect was more prominent when a task required more precise movement on the tablet (see Table 17).
3. The mode and subtask interaction effects showed that the difference between subtask performances was at the largest on lift-off plus enter mode and at the smallest on lift-off plus key mode.

Figure 7: Average response time per trial

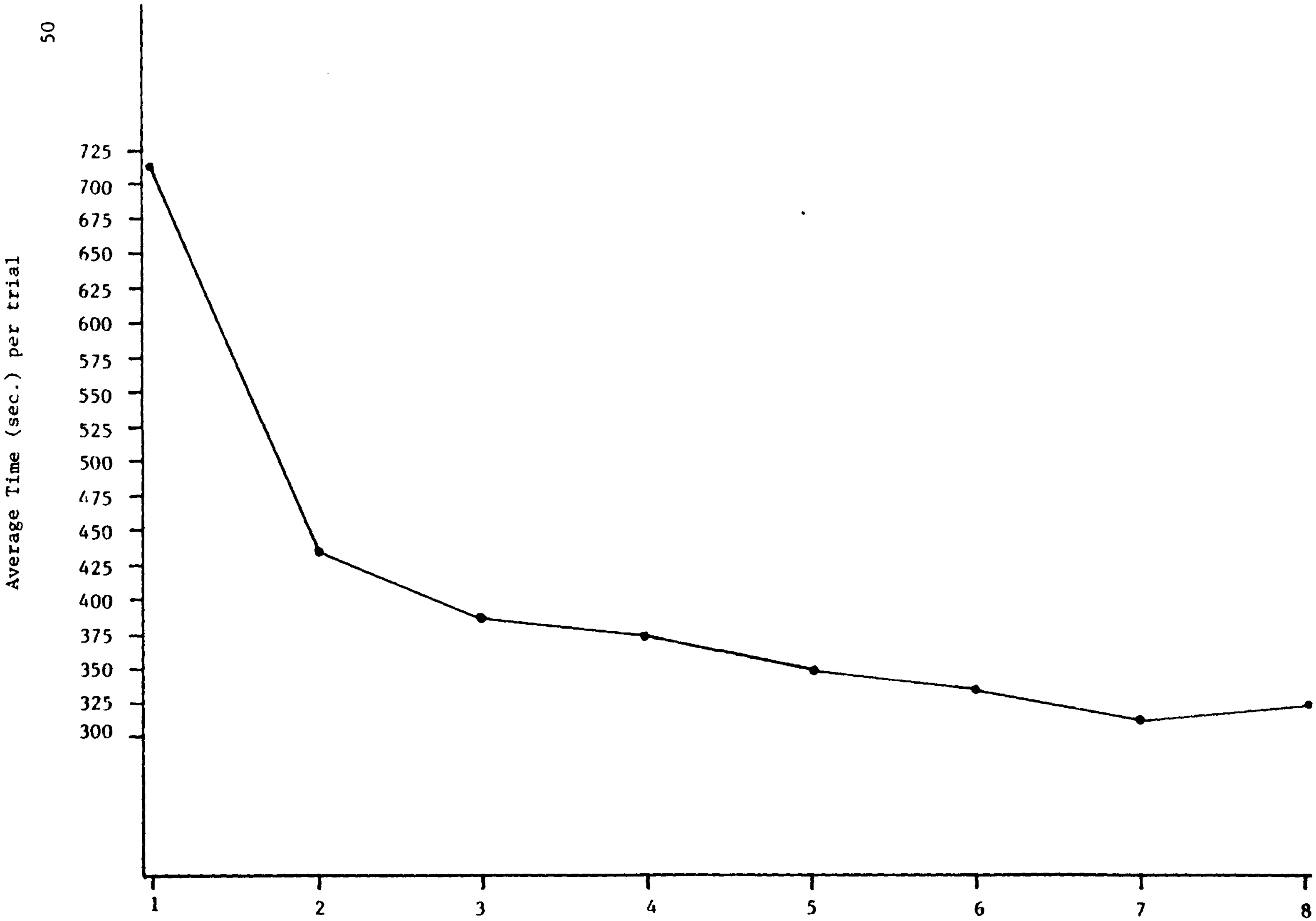


TABLE 12

Analysis of Variance for Trial Completion Time

SOURCE	DF	MS	F
GENDER	1	13786.71	2.35
STYLUS	1	22347.08	3.81
MODE	2	247229.30	42.16****
GENDER*STYLUS	1	4977.70	0.85
STYLUS*MODE	2	6832.87	1.17
GENDER*MODE	2	8554.85	1.46
GENDER*STYLUS*MODE	2	3374.96	0.57
ERROR	48	5863.23	

**** P § 0.0001

Figure 8: Average response time as a function of data insertion mode.

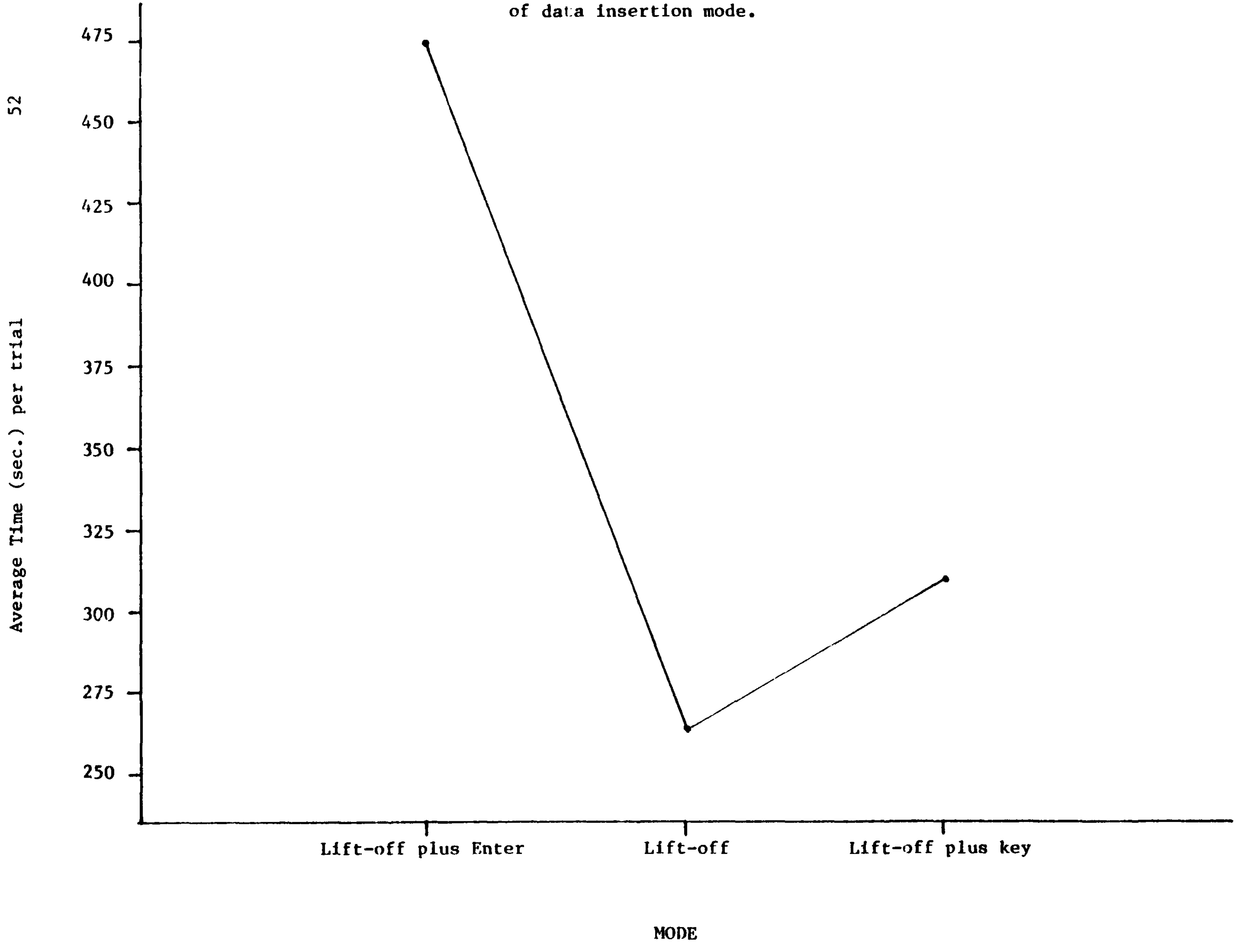


TABLE 13

Analysis of Variance for Alphanumeric Data Entry Subtasks

SOURCE	DF	MS	F
BETWEEN SUBJECTS			
GENDER	1	4379.60	2.16
MODE	2	86213.66	42.55****
GENDER*MODE	2	2590.62	1.28
STYLUS	1	9508.52	4.69*
GENDER*STYLUS	1	1049.30	0.52
STYLUS*MODE	2	2743.79	1.35
GENDER*STYLUS*MODE	2	858.59	0.42
SUBJ.W.GROUP	48	2026.36	
WITHIN SUBJECTS			
DTYPE(ALPHABETIC VS NUMERIC)	1	13652.55	100.87****
GENDER*DTYPE	1	24.00	0.18
MODE*DTYPE	2	641.21	4.74*
STYLUS*DTYPE	1	5.90	0.04
GENDER*MODE*DTYPE	2	273.27	2.20
GENDER*STYLUS*DTYPE	1	31.19	0.23
STYLUS*MODE*DTYPE	2	141.91	1.05
GENDER*STYLUS*MODE*DTYPE	2	124.55	0.92
DTYPE*SUBJ.W.GROUP	48	135.35	

**** p § 0.0001; * p § 0.05

Figure 9: Average response time as a function of data insertion mode and data type (data entry tasks only).

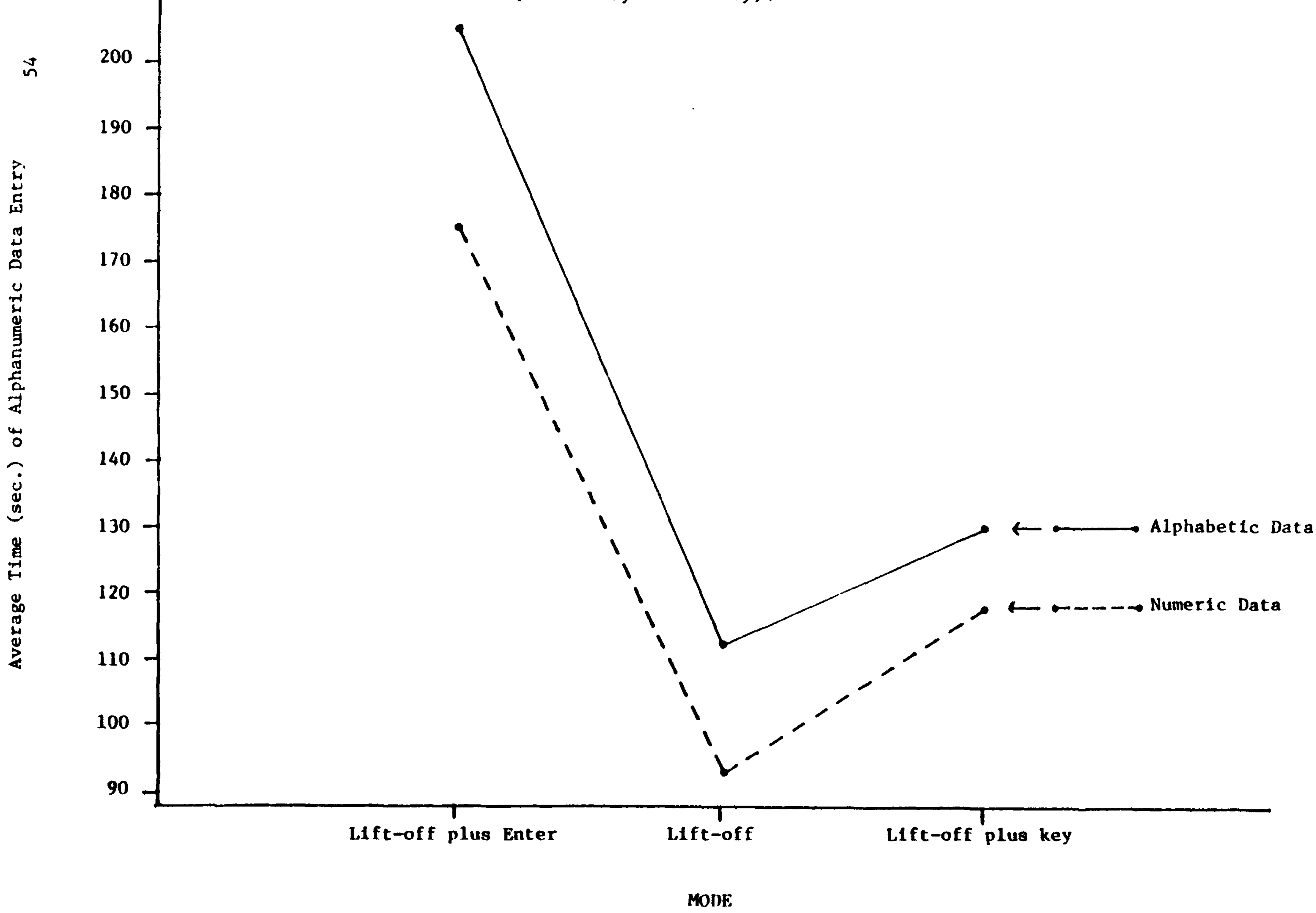


Figure 10: Average response time as a function of stylus type and data type (data entry tasks only).

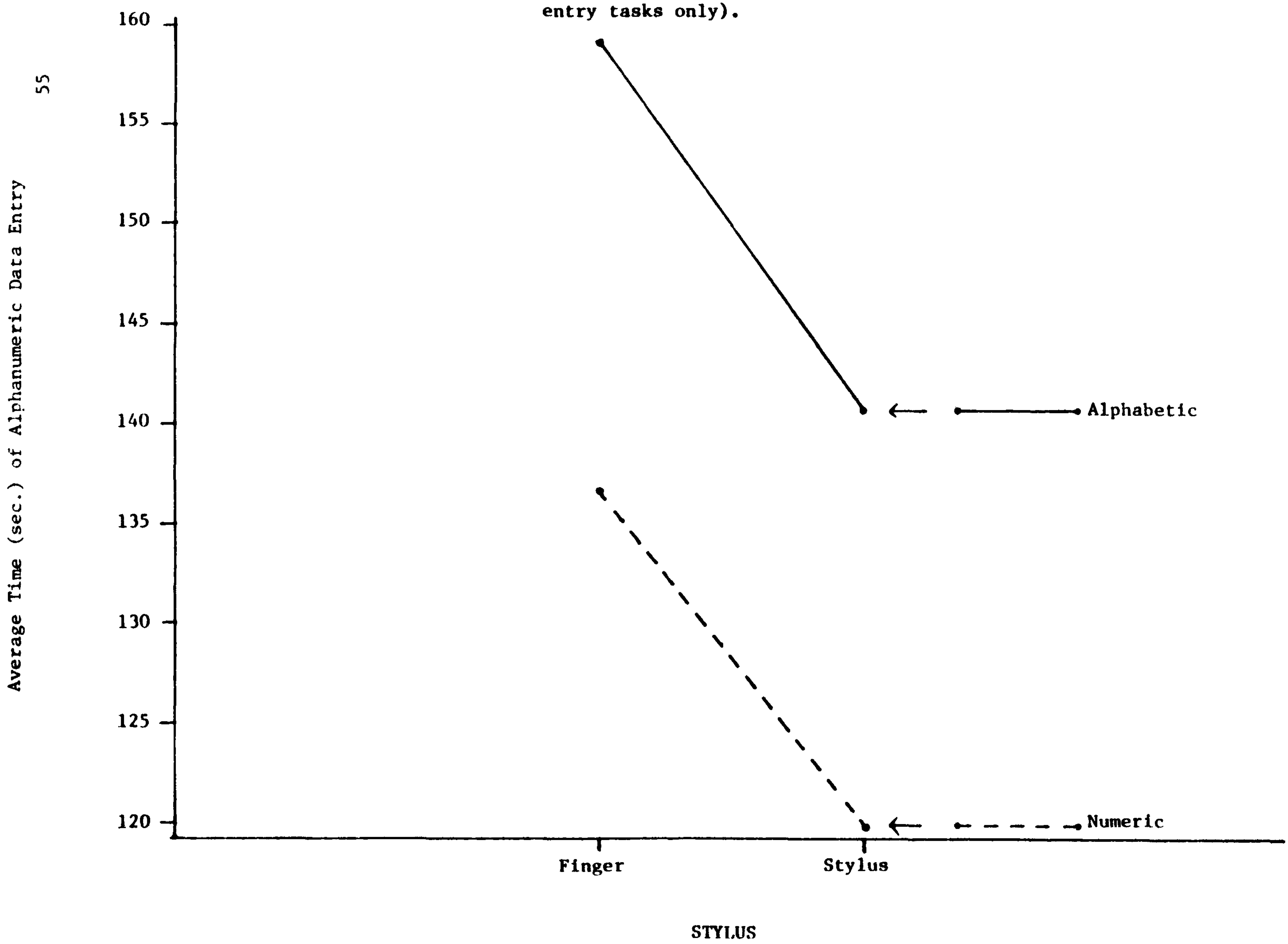


TABLE 14

Analysis of Variance for Function Selection Subtasks

SOURCE	DF	MS	F
BETWEEN SUBJECTS			
GENDER	1	9.79	1.92
MODE	2	163.22	32.07****
GENDER*MODE	2	10.62	2.09
STYLUS	1	4.74	0.93
GENDER*STYLUS	1	10.16	2.00
STYLUS*MODE	2	3.89	0.77
GENDER*STYLUS*MODE	2	7.21	1.42
SUBJ.W.GROUP	48	5.09	
WITHIN SUBJECTS			
ENTRY(SINGLE VS DUAL)	1	10.09	16.78****
GENDER*ENTRY	1	1.39	2.32
MODE*ENTRY	2	2.01	3.35*
STYLUS*ENTRY	1	0.05	0.09
GENDER*MODE*ENTRY	2	1.26	2.13
GENDER*STYLUS*ENTRY	1	1.92	3.20
STYLUS*MODE*ENTRY	2	0.54	0.90
GENDER*STYLUS*MODE*ENTRY	2	1.21	2.01
ENTRY*SUBJ.W.GROUP	48	0.60	

**** p § 0.0001; * p § 0.05

TABLE 15

Analysis of Variance for Single Entry Data

SOURCE	DF	MS	F
BETWEEN SUBJECTS			
GENDER	1	26.39	2.31
MODE	2	483.19	42.25****
GENDER*MODE	2	20.48	1.79
STYLUS	1	34.21	2.99
GENDER*STYLUS	1	13.59	1.19
STYLUS*MODE	2	10.99	0.96
GENDER*STYLUS*MODE	2	9.33	0.82
SUBJ.W.GROUP	48	11.44	
WITHIN SUBJECTS			
TYPE(LETTER,DIGIT,SINGLE,DUAL)	3	41.17	45.77****
GENDER*TYPE	3	0.66	0.74
MODE*TYPE	6	7.11	7.90****
STYLUS*TYPE	3	2.58	2.87*
GENDER*MODE*TYPE	3	0.87	0.96
GENDER*STYLUS*TYPE	3	0.91	1.01
STYLUS*MODE*TYPE	6	1.57	1.75
GENDER*STYLUS*MODE*TYPE	6	0.98	1.09
TYPE*SUBJ.W.GROUP	144	0.90	

**** p § 0.0001; * p § 0.05

Figure 11: Average response time per entry as a function of data insertion mode and task type.

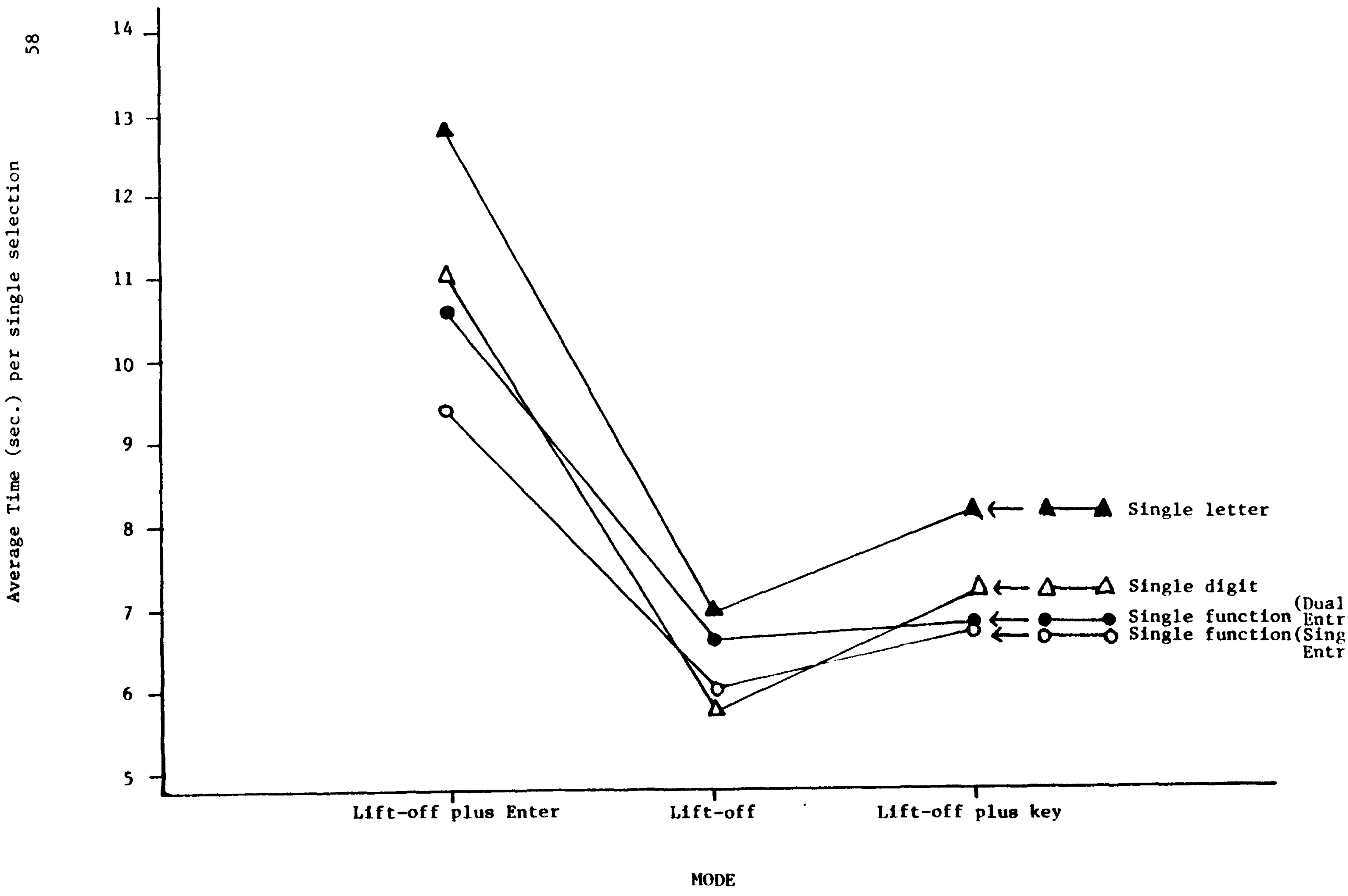


Figure 12: Average response time per entry as a function of stylus type and task type.

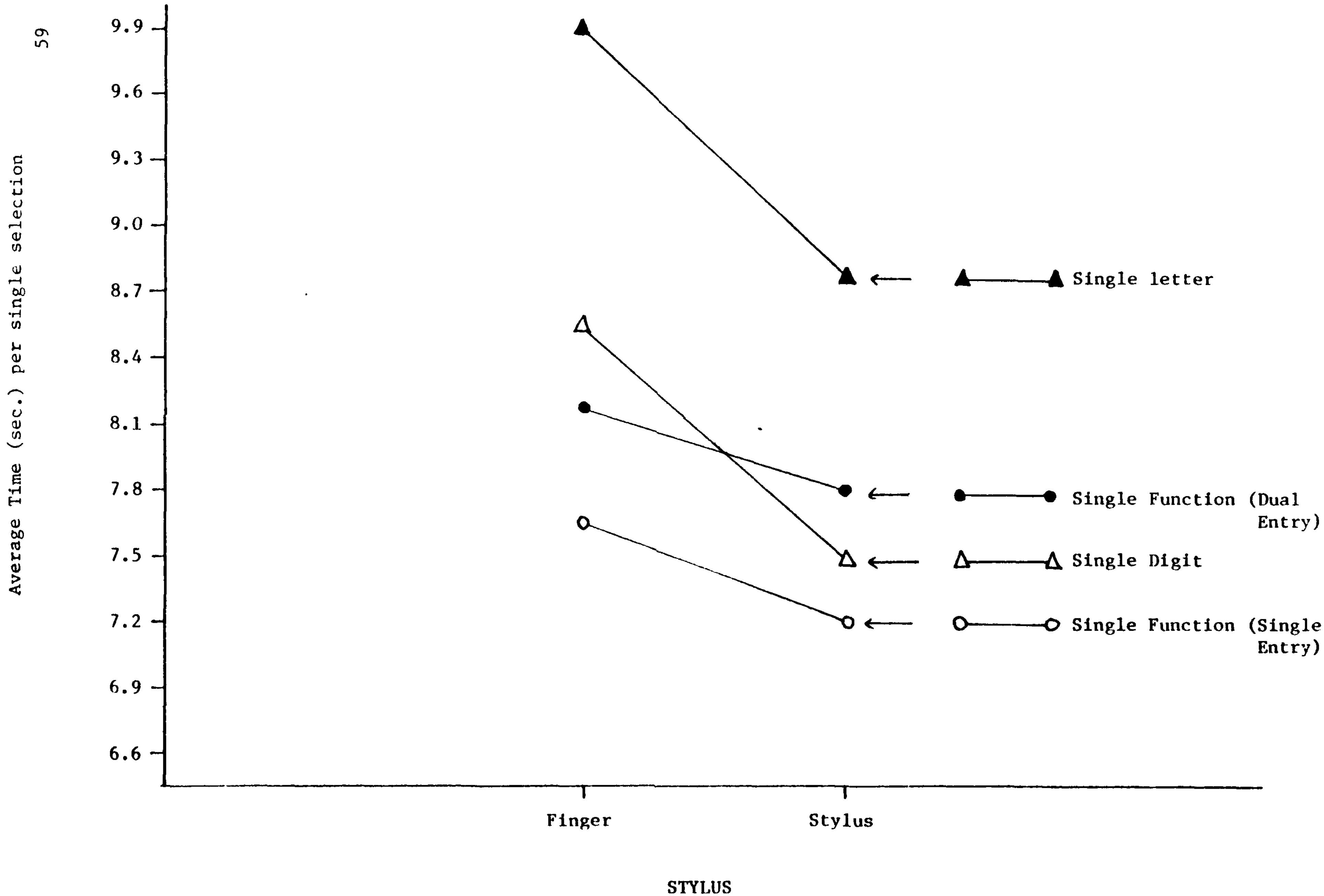


TABLE 16

Means(sec) & Standard Deviations under the Mode Variable

	MODE		
	LIFT-OFF+ENTER	LIFT-OFF+KEY	LIFT-OFF
TASK	MN(SD)	MN(SD)	MN(SD)
TC	474.52 (112.02)	310.01 (70.24)	262.71 (38.34)
SFS	9.47 (1.99)	6.70 (0.96)	6.02 (0.78)
SFD	10.53 (3.20)	6.88 (1.00)	6.52 (1.31)
AD	206.18 (54.56)	130.68 (32.20)	112.20 (19.91)
ND	176.21 (36.06)	116.52 (32.80)	92.34 (13.14)
AS	12.89 (3.41)	8.17 (2.01)	7.01 (1.24)
NS	11.01 (2.25)	7.28 (2.05)	5.77 (0.82)

TC : Trial Completion Time

SFS : Single Function Selection (Single Entry)

SFD : Single Function Selection (Dual Entry)

AD : Alphabetic Data Entry

ND : Numeric Data Entry

AS : Single Letter Entry

NS : Single Digit Enrty

TABLE 17

Means(sec) & Standard Deviations under the Stylus Variable

	STYLUS	
	FINGER	STYLUS
TASK	MN(SD)	MN(SD)
TC	368.38 (130.95)	329.77 (107.46)
SFS	7.62 (2.31)	7.18 (1.66)
SFD	8.15 (3.34)	7.80 (2.01)
AD	158.81 (60.84)	140.56 (49.35)
ND	137.03 (47.68)	119.67 (42.56)
AS	9.92 (3.80)	8.78 (3.08)
NS	8.56 (2.98)	7.47 (2.65)

TC : Trial Completion Time

SFS : Single Function Selection (Single Entry)

SFD : Single Function Selection (Dual Entry)

AD : Alphabetic Data Entry

ND : Numeric Data Entry

AS : Single Letter Entry

NS : Single Digit Entry

DISCUSSION

The four studies included in the present research project have assessed a variety of operational parameters of the touch-tablet in tasks related to command and control functions. These parameters include:

1. Mode of Operation: The system may be programmed to input x-y coordinates commanding cursor movement which are relative to the tablet's surface area (Absolute Mode), or to input x-y coordinates proportional to the change in stylus movement on the tablet, irrespective of the specific part of the tablet touched.
2. Data Insertion Mode: The computer may be commanded to accept data input in a variety of ways. The modes considered were: Lift-Off Only, Lift-Off Plus Enter (on the tablet), Lift-Off Plus Separate Enter Key,, and Separate Enter Key Without Lift-Off.
3. Stylus Type: The tablet may be actuated by any form of mechanical pressure exceeding the 4 ounce threshold. Both unaided finger and hand-held stylus were evaluated in the present studies.
4. Type of Task: The four experiments considered a variety of tasks including: simple cursor

single function selection, multiple function selection, and alphanumeric data entry.

Although it had been intended to examine system response time as an additional parameter of tablet operation, pilot work revealed that the hardware/software used to implement the simulated LMDS system imposed a delay in reading x-y coordinates from the tablet which was longer than the values of SRT of interest.

The results of Experiment I.B clearly demonstrated the superiority of the absolute mode of tablet operation, and the remaining studies in the series considered only this method of generating touch tablet input to the system. Tracking under the absolute mode resulted, on the average, in less than one-half the RMS error as did performance under the relative mode. The direct representation of the display on the control surface appears to be the optimum configuration of the touch tablet system. Most of the tasks used in the present studies presented control/display ratios of approximately 1.0.

A large number of schemes can be devised to signal the computer system to accept input from the tablet surface. The simplest method consists of directing the system to accept the x-y coordinate generated at the instant the finger or stylus is removed from the tablet surface (Lift-

acceptance by the computer system and in the present studies the x-y samples obtained during the 200 milliseconds prior to "lift-off" were discarded to eliminate this source of error. Another method of "inserting" data into the human - computer system, involves the use of a separate response that confirms the command to the system to accept the x-y coordinate generated by actuating the tablet surface. Three variations of a confirmation command were examined in the present studies: (1) lift-off combined with the touch actuation of an "enter" zone on the tablet surface; (2) lift-off combined with the depression of a momentary contact switch mounted beside the tablet, and (3) depression of the momentary contact switch prior to lifting the finger/stylus from the x-y position desired.

As might be expected a trade-off between response speed and accuracy was observed as a function of data insertion mode. In Experiment I.A Lift-Off only produced the fastest responses but was associated with the most errors when subjects operated the tablet with the unaided finger. No difference in error rate was observed between data insertion modes when subjects used a hand-held stylus. In Experiment II, which contrasted all four data insertion modes, the slowest procedure was lift-off plus separate enter on the

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Whitfield, et al., 1983

tablet while the fastest responding was associated with the use of a separate off-tablet enter key without stylus lift-off from the tablet. Lift-off only and lift-off plus separate enter key were also associated with rapid rates of responding. The fewest errors were, conversely, associated with lift-off plus separate enter on the tablet surface, although the only extremely high error rate was associated with lift-off only, particularly for alphameric data.

In Experiment III lift-off plus enter on the tablet produced the slowest responding for all task and data types, while lift-off only produced the fastest responding. Lift-off plus off-tablet enter key produced a rate of response only slightly slower than lift-off only. On the basis of these results it would appear that the double responding required by the use of a confirmation response on the tablet surface is unacceptably slow. When suitable error correction procedures (e.g., provision to re-enter faulty data, etc.) are available it is likely that lift-off only will be the preferred method of signalling data insertion. If insurance against erroneous data entries is a design priority, the use of a separate off-tablet entry key is probably the desired choice.

All of the studies in this series contrasted response with the unaided finger versus the use of a hand-held stylus. In virtually every instance faster and more accurate responding was observed when subjects used the

hand-held stylus. The stylus used in each study was an 85 mm long plastic tube with a diameter of 20 mm. The tip of the stylus was a 10 mm diameter plastic ball-bearing. One explanation for the superiority of the stylus may be the difference in the effective contact area on the tablet surface. The tablet/controller combination used in these studies records (as the x-y position of each sample) the centroid of the area of the tablet surface distorted by pressure of the actuator mechanism. The tip of the finger affects a larger area than does the hard plastic ball-bearing of the stylus and less precise x-y positioning is possible with the finger. Further, the effective contact area of the finger may vary significantly as a function of amount of pressure exerted, while the contact area of the stylus is relatively constant across a wide range of pressures.

It is also possible that the nature of the motor movements required in the operation of the finger as opposed to the stylus may account for the difference in performance. Use of the finger to actuate the touch tablet requires movement of the entire arm, with particular emphasis on the elbow and shoulder, and a tendency to hold the wrist and fingers in a fixed position. Use of the stylus allows for greater wrist and finger movement, particularly for fine adjustments, although manipulation of the stylus across the entire tablet surface also requires gross adjustment movements of the elbow and shoulder.

Whichever explanation may prove correct it seems clear that superior performance is obtainable with a simple, inexpensive stylus. Certainly research with the touch tablet should control this parameter of tablet operation and not permit subjects uncontrolled choice between finger and stylus. It seems reasonable also to further examine this result and compare different types of styli.

When the several types of tasks are compared, as was the case in Experiment III, it would appear that the basic level of response speed is fairly comparable across tasks. Under the fastest data insertion mode (Lift-off only) mean entry times (see Table 16) ranged from 5.77 seconds for single numeric digits, to 6.02 seconds for single function seletion, to 6.52 seconds for dual function selection, to 7.01 seconds for single alphameric characters. These per entry times increase to a range from 9.47 (single function selection) to 12.89 seconds (alphameric character entry) under the lift-off plus enter on-tablet data insertion mode. While these rates of response are only modest in comparison to function keys or a keyboard for discrete data entry tasks, it must be acknowledged that the same device (touch tablet) is a reasonably efficient controller for the two dimensional tracking task used in Experiment I.B., when configured to input x-y coordinates in an absolute mode of operation. The advantage of the touch tablet seems therefore to lie in its general facility for a wide range of tasks.

It must be noted that all of the tasks considered in this series of investigations utilized an unlabelled touch tablet to effect the movement of a cursor on the display screen. Despite the range of operations performed (alphanumeric data entry to function selection to tracking) all of these tasks involve relatively simple cursor positioning. The fact that the per entry time is relatively constant between tasks argues for this commonality among the touch tablet operations considered here. It is possible, however, to configure the touch tablet in ways which change the nature of the basic psychomotor task. Tablet labelling, for example, would change the nature of function selection and discrete data entry tasks. It would be useful to examine this variation in the operational use of the touch tablet.

The present studies also used relatively simple displays which did not require fine discrimination between active areas on the touch tablet surface (alternate functions or characters to be selected were fairly widely separated). Additional research is needed to define the practical density of active areas on the tablet surface, and to determine how much inactive or 'dead' area should seperate functions or characters on the tablet surface.

Finally, the influence of system response time on various modes of touch tablet operation remains to be examined. While fairly significant software lags precluded the manipulation of system response time in the present studies,

it is quite possible that this variable may be important in systems which require, and respond, to more rapid rates of response.

Appendix A

THE FLOWCHART AND THE SCREENS USED FOR EXPERIMENT III

```
                    START
                      |
ALERT SELECT       <---     AIR
(OPTION:OUTERSPACE, AIR, SURFACE, UNDERWATER)
                      |
COMMAND                     SELECT
                      |
COMBAT                      REVIEW
                      |
COMBAT CLASSIFICATION<--- WPN SELECT
                      |
COMBAT                      ENTRY
                      |
TYPE               <---     MISSILE
                      |
CODE1:BCEGZ,CODE2:DFAYK,CODE3:JLNOQ
                      |
GROUP              <---     SAM
(OPTION:SSM,SAM,SUM, USM, AAM, ASM, AUM, UAM)
                      |
GEOMETRY           <---     COORDINATE
                            X<--- 58076
                            Y<--- 69432
                            Z<--- 37514
                      |
                    STOP
```

Figure A-1. Flowchart for selection and data entry tasks in Experiment III.

Figure A.2: Screen 1

MENU:ALERT
SELECT

SELECT AN
OPTION FROM
THE ARRAY
SHOWN BELOW

SELECT "AIR" FROM THE LIST BELOW

OUTERSPACE	AIR
SURFACE	UNDERWATER

Figure A.3: Screen 2

MENU:ALERT SELECT		SELECT AN OPTION FROM THE ARRAY SHOWN BELOW
	SELECT "COMBAT SELECT" FIRST, THEN SELECT "COMBAT REVIEW"	
COMMAND SELECT		COMBAT REVIEW

Figure A.4: Screen 3

MENU:COMBAT REVIEW		SELECT AN OPTION FROM THE ARRAY SHOWN BELOW
	SELECT "WPN SELECT FIRST, THEN SELECT "COMBAT ENTRY"	
	CONTROL________________________	
	TRACK__________________________	
	DISPLAY________________________	
	ID_____________________________	
	WPN SELECT_____________________	
COMMAND SELECT		
COMBAT REVIEW		COMBAT ENTRY

Figure A.5: Screen 4

MENU:COMBAT ENTRY

SELECT AN OPTION FROM THE ARRAY SHOWN BELOW

SELECT "MISSILE"

TYPE:__________
CODE1:_________
CODE2:_________
CODE3:_________
GROUP:_________
GEOMETRY:______

>SELECT OPTION:
(TYPE)

MISSILE
NUCLEAR WPN
LASER WPN

COMMAND SELECT

COMBAT REVIEW

COMBAT ENTRY

Figure A.6: Screen 5

MENU:COMBAT ENTRY		SELECT AN OPTION FROM THE ARRAY SHOWN BELOW
	SELECT "KEYBOARD"	
	TYPE:MISSILE CODE1:________ CODE2:________ CODE3:________ GROUP:________ GEOMETRY:______	
COMMAND SELECT		KEYBOARD
COMBAT REVIEW		
COMBAT ENTRY		

Figure A.7: Screen 6

MENU:COMBAT ENTRY

SELECT AN OPTION FROM THE ARRAY SHOWN BELOW

1st. SELECT "B,C,E,G,Z" FOR CODE 1
2nd. SELECT "D,F,A,Y,K" FOR CODE 2
3rd. SELECT "J,L,N,O,Q" FOR CODE 3
4th. SELECT "COMPLETE"

<u>**TYPE:MISSILE**</u>
CODE1:________
CODE2:________
CODE3:________
GROUP:________
GEOMETRY:

A	B	C
D	E	F
G	H	I
J	K	L
M	N	O
P	Q	R
S	T	U
V	W	X
Y	Z	

COMMAND SELECT

COMBAT REVIEW

COMBATE ENTRY

COMPLETE

Figure A.8: Screen 7

MENU:COMBAT ENTRY

SELECT AN OPTION FROM THE ARRAY SHOWN BELOW

SELECT "SAM"

TYPE:MISSILE
CODE1:ECEGZ
CODE2:DFAKY
CODE3:JINGC
GROUP:________
GEOMETRY:

>SELECT OPTION:
(GROUP)

SSM	AAM
SAM	ASM
SUM	AUM
USM	UAM

COMMAND SELECT

COMBAT REVIEW

COMBAT ENTRY

Figure A.9: Screen 8

MENU:COMBAT ENTRY

SELECT AN OPTION FROM THE ARRAY SHOWN BELOW

SELECT "COORDINATE"

TYPE:MISSILE
CODE1:BCEGZ
CODE2:DFAYK
CODE3:JLNCC
GROUP:SAM
GEOMETRY:
COORDINATE:

>SELECT OPTION:
(GEOMETRY)

BRG
UNIV
RNG
COORDINATE

COMMAND SELECT

COMBAT REVIEW

COMBAT ENTRY

Figure A.10: Screen 9

MENU:COMBAT ENTRY

1st. SELECT "5,8,0,7,6" FOR X
2nd. SELECT "6,9,4,3,2" FOR Y
3rd. SELECT "3,7,5,1,4" FOR Z
4th. SELECT "COMPLETE"

TYPE:MISSILE
CODE1:ECFGZ
CODE2:DFAYK
CODE3:JINCC
GROUP:SAM
GEOMETRY:
COORDINATE:
X : 58076
Y : 69432
Z : 37514

SELECT AN OPTION FROM THE ARRAY SHOWN BELOW

1	2	3
4	5	6
7	8	9
0	ENTER	

COMMAND SELECT

COMBAT REVIEW

COMBAT ENTRY

COMPLETE

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